

Control Processing System Architecture for the Optical Communications Demonstrator

LecAnn Voisin

Jet Propulsion Laboratory, California Institute of Technology
4800 Oak Grove Drive, Pasadena, CA 91109

AIMTRACT

A processing system was designed and implemented to support beacon acquisition, precision beam pointing, and command/control functions for the Optical Communications Demonstrator. The central processor operates as a command controlled embedded system, but by blending real-time and linear design techniques, a single digital signal processor handles all spaceborne functions. Real-time functions include operation of a CCD array detector, calculation of centroids, computation of point-ahead error, and execution of a steering mirror servo loop at 2 kHz update rate. Linear functions include command interpretation, diagnostic control of all functions, storage and interpolation of data for acquisition and point-ahead calculation, downlinking of status information, hardware control, transmit laser control, and image capture.

1. INTRODUCTION

The Optical Communications Demonstrator (OCD) is designed to demonstrate key elements of a spacecraft optical communications system in a laboratory environment. The reduced complexity design includes beacon signal acquisition, high bandwidth spatial tracking, precision beam pointing with point ahead angle compensation, and downlink of a modulated signal. This paper discusses the processing system architecture and software design that directs and accommodates these functions.

The OCD instrument is designed to maintain architecture, form, and function of a space flight instrument; this dictates that the processing system must have two clearly separate domains, the Control Terminal (CT) and System Control Assembly (SCA). The SCA is based on a TMS320C40 digital signal processor; it operates as a true command driven embedded system, all communications and data are transferred through a full duplex link that simulates the interface between the OCD instrument and the host spacecraft. The SCA controls and monitors all instrument functions, the most significant of which are real-time operation of CCD array and centroiding to maintain a servo-loop update rate of 2 kHz. The CT is executed on an 80486 PC with a TMS320C30 subsystem; its purpose is to simulate the spacecraft side of the communications link. It supplies commands, spacecraft attitude updates, and ephemerides data; it interprets downlinked data, tracking statistics, hardware status, and images.

This design uses a blend of real-time and linear processing techniques to maximize the use of the TMS320C40 processor. Essentially, the software adjustable frame rate (i.e. servo loop update rate) becomes a "heartbeat" for the entire SCA. With each "heartbeat" the system executes certain real-time functions at preset intervals, while using other intervals to execute non-time-critical linear functions in remaining time.

2. OCD PROCESSING SYSTEM REQUIREMENTS

Though the OCD is described as a reduced complexity design, it does represent an architecture for a spaceborne instrument. Therefore the system must execute all functions necessary in a spacecraft environment. A Control Terminal (CT) is used to simulate the host spacecraft, the System Control Assembly (SCA) is the processing unit for the spaceborne instrument. The requirement for high bandwidth spatial tracking requires that certain real-time functions dominate the processing system requirements.

The CT must provide a user interface with the OCD instrument providing a command and data interpreter for the OCD instrument. It must simulate the host spacecraft, provide attitude updates at 10 Hz, forward all ground control commands

and, receive all **downlinked** data. It must also **simulate** ground control functions and provide ephemerides updates, allowing ground control to execute operational and diagnostic commands.

The SCA **must** retrieve command strings from the spacecraft (CT). It must downlink **status** information, tracking statistics, and image data. It must perform spot locating and differentiation for spatial acquisition of the beacon signal, including all interpolations from ephemerides and spacecraft attitude information. While tracking, it must retrieve digitized image data from the tracking detector (CCD array), calculate **centroids** for the transmit laser and **uplink** beacon, and execute a steering mirror servo-loop at 2 kHz update rate for fine pointing of the transmit laser. The coarse pointing (gimbal) control loop must **be** executed to stabilize the **line** of sight at 100-200 Hz update rate. Hardware control functions **include**: operation of steering mirror, enable/disable of transmit laser, gimbal control, and monitoring of instrument status.

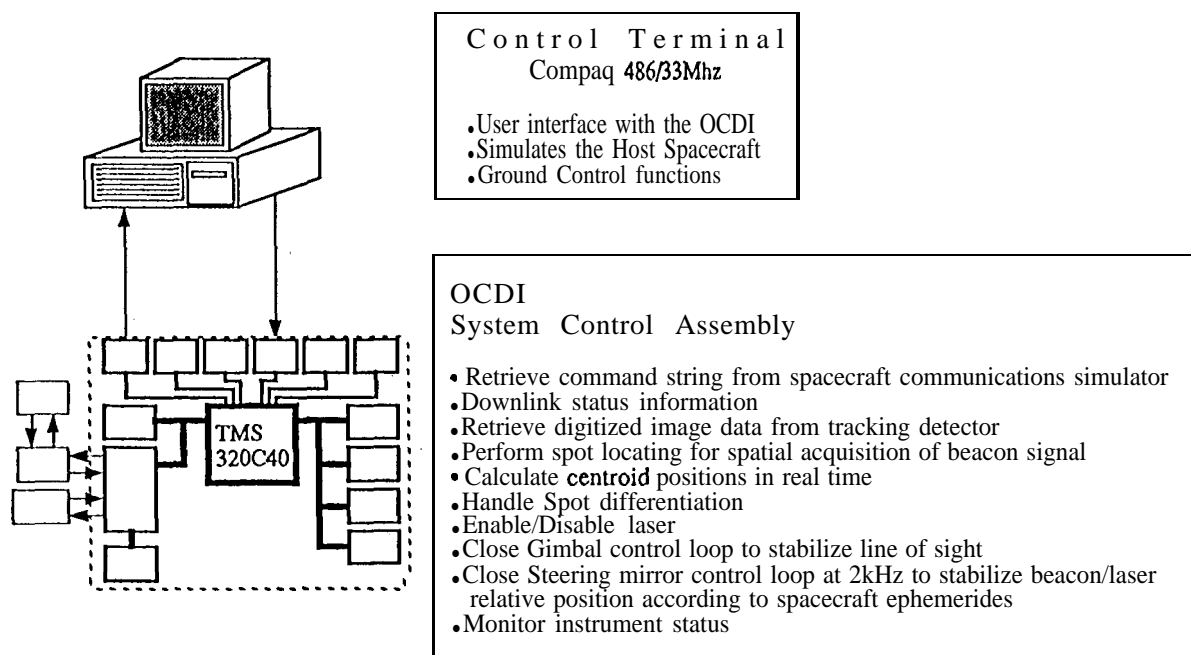


Fig 1. OCD software and processing system operational requirements

3. CONTROL TERMINAL

The CT (control terminal) is the interface between user and OCD. Essentially, the CT is a **menued** interpreter made up of two components, a Compaq Deskpro 80486/33 Ml Iz IBM compatible PC and a DIPIX Power Grabber (digital signal processor and frame grabber).

The PC provides the platform and user interface, allowing the user to operate the OCD instrument, exercise manual commands, monitor status, and request statistics (all while engaging in acquisition and tracking). The PC also stores tracking and communications statistics for later analysis.

Imaging and OCD communications are handled through the DIPIX board. Images are displayed on an EGA monitor connected directly to the DIPIX board. The DIPIX board also conducts communications with the OCD instrument across a DT-connect interface.

Since the control terminal acts purely as an interpreter—providing an interface for the user and mimicking the spacecraft for the OCD instrument—it was not necessary to work with “flight qualifiable” components, so commercial

products were used for speed and economy in development. Menuing and C++ programming were done using Borland's C++ compiler and Turbovision menu developer.

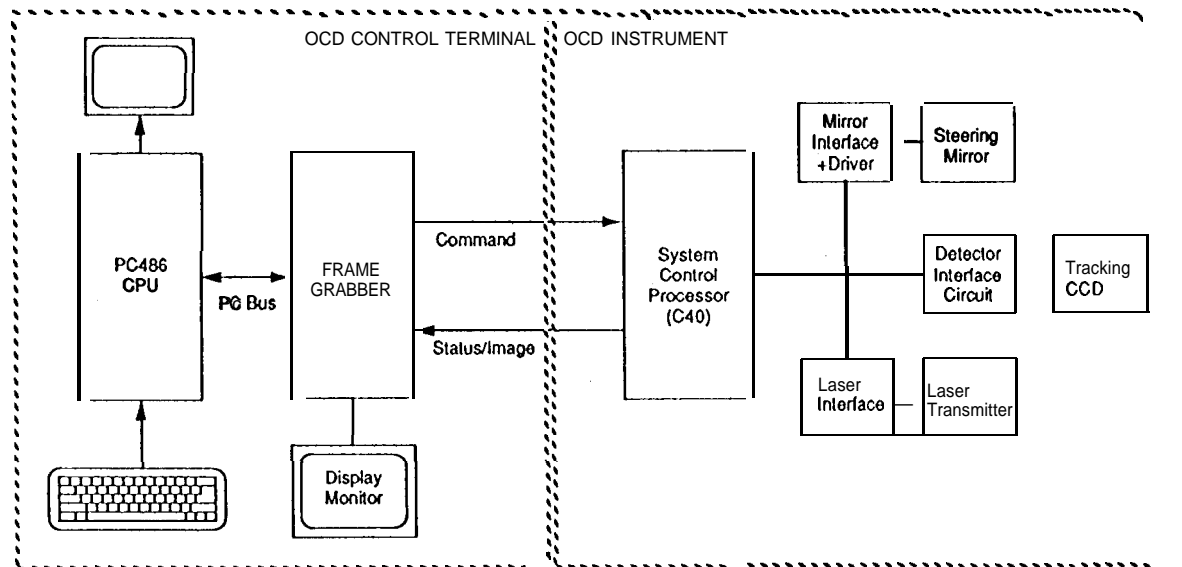


Fig 2. Operational Architecture for OCD

4. SYSTEM CONTROL ASSEMBLY

The SCA (system control assembly) is the processing "heart" for the Optical Communications Demonstrator. It has been initially implemented with an Ariel "Cyclops" TMS320C40 based DSP board. For development, it is housed in a Compaq Deskpro 80386 IBM compatible PC; when in operation its operation is independent of the PC.

This "heart" beats at precisely the desired frame rate of the tracking system, continuously imaging with the CCD array. All tracking functions (centroiding, compensation, steering mirror correction) are executed in real-time. The real-time functions occur in a predictable order and at known intervals. Below is an ordered list of these functions as they occur in the tracking mode.

1. Initiate frame transfer
Using DMA transfer, vertically shift (without reading) enough lines to pull image into storage plane of CCD array.
2. Read pixel values from windows of interest
Vertically and Horizontally shift storage plane only, to obtain pixel values in windows of interest. Note that horizontal shifts only occur when necessary to gain access to pixels in windows of interest.
3. Centroid windows
Calculate centroids for windows, then move windows so that they are centered over the newly calculated centroid.
4. Execute steering mirror compensation filter
Calculate point ahead error and submit to compensation filter. Move steering mirror based on filter output, to obtain proper point ahead.

The Linear functions are cycled through "housekeeping" slots which occur during the frame transfer. This allows a single DSP processor to handle both linear and real-time functions. Linear functions not completed during the allotted time

are bookmarked, and execution continues during the next "housekeeping" slot. Linear functions include command interpretation, hardware status and data downlinking, diagnostic routine operations, and monitoring of all functions. When implemented, gimbal operation will operate during this "housekeeping" time, taking 1/20 of all housekeeping slots. Note that point ahead calculation (interpolation from ephemerides and spacecraft attitude information) occurs in each frame, during the first available time after the frame transfer begins.

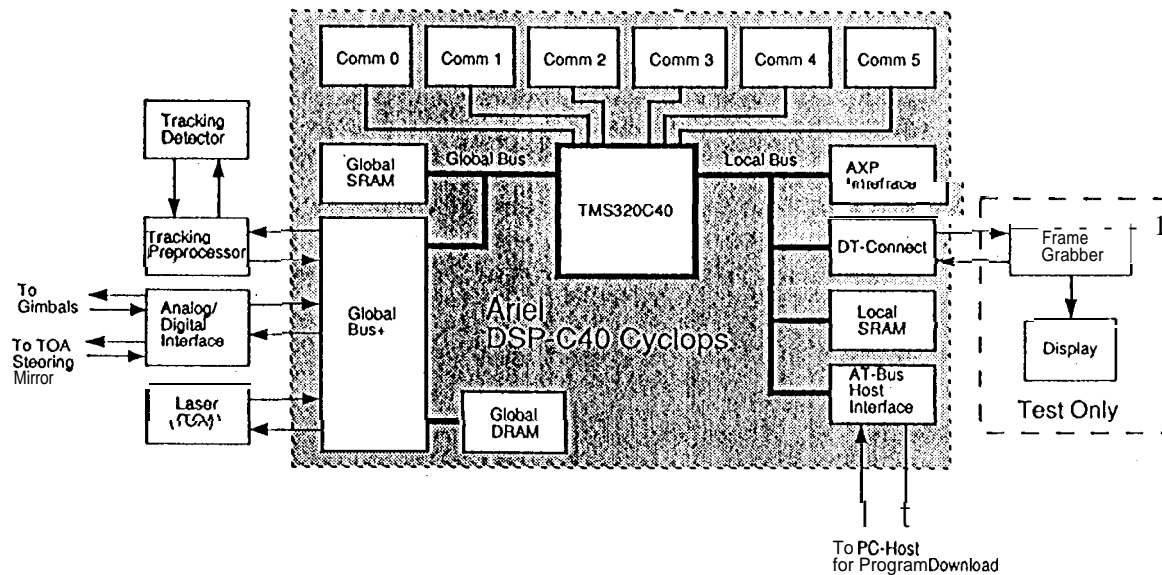


Fig 3. System Control Assembly (SCA)

5. PROCESSING BUDGET & CENTROIDING ALGORITHMS

When tracking is engaged, the SCA operates on a strict processing budget based on the chosen servo loop update rate of 2 kHz. This requires that the SCA complete all real-time tasks (reading of CCD array, centroiding, compensation filter operation, and steering mirror correction) in less than 500 μ s. The centroiding algorithm takes the majority of the 500 μ s, the time for the centroiding algorithm includes reading the pertinent windows from the CCD array. No pixel values are stored, the information is used at the time it is read.

The basic centroid equation is given by,

$$X_c = \frac{\sum [(PixelValue)(L_x)]}{\sum [PixelValue]} + X_b + \left(\frac{W}{2}\right) \quad (1)$$

$$Y_c = \frac{\sum [(PixelValue)(L_y)]}{\sum [PixelValue]} + Y_b + \left(\frac{H}{2}\right) \quad (2)$$

where (X_c, Y_c) are the coordinates on the CCD of the centroid in the window of interest, *PixelValue* is the actual pixel data from the CCD, (L_x, L_y) represents the coordinates of the pixel being accessed, the sums are over the window of

interest, (X_b, Y_b) are the 10WCSL index corner of the window of interest, and (W, H) represents the size of the window in pixels. The algorithm can be further refined by replacing *PixelValue* with *PixelValue-B* where *B* is the background level,

The background level is approximated by averaging the border pixels of each window, this information is used for acquisition, spot discrimination, and thresholding. The equation is given by:

$$B = \frac{\sum [PixelValue]}{2(W + H) - 4} \quad (3)$$

where *B* is the background approximation, the denominator represents the number of pixels in the border of the window, and the sum is over all pixels in the border of the window of interest.

The processing time budget is dictated by the frame rate, which is adjustable in software. It is shown below in Figure 4. Note that fine pointing is completed in the current frame. Coarse pointing (gimbal) can be completed during the housekeeping slots if necessary, at a much lower update rate. Since the windows of interest can occur anywhere over the 100x 100 pixel array, a "worst case" involves reading 2 vertically separated windows, with one of these in a corner that requires shifting the last pixel out of the storage plane. With 6x6 windows, we have allowed 339 μ s for this "worst case".

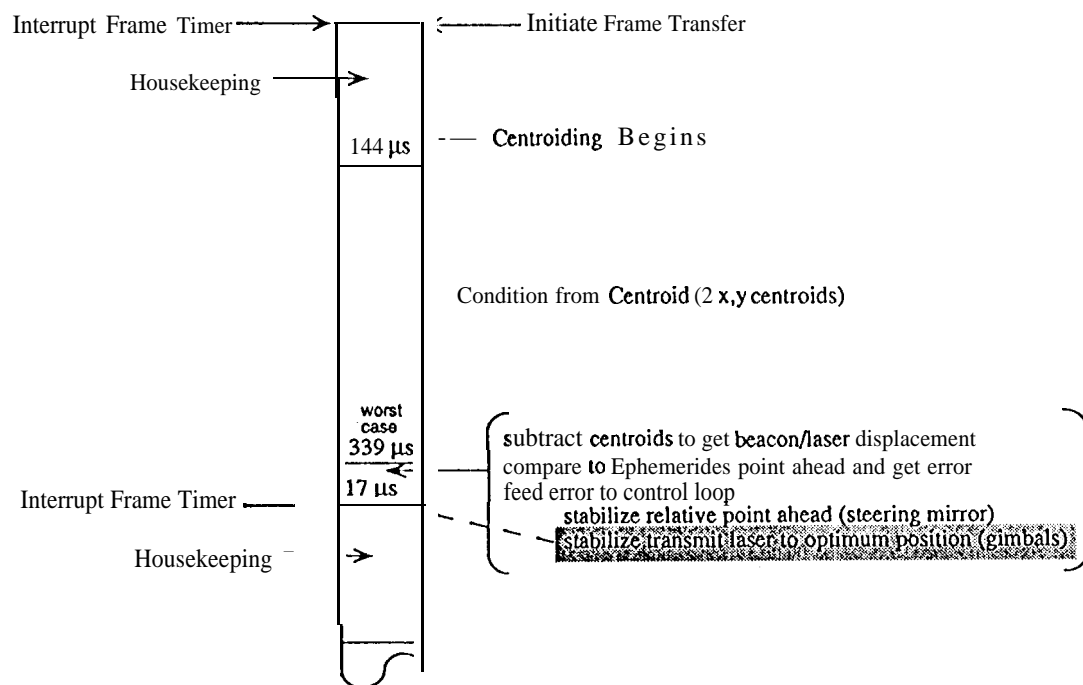


Fig. 4 Processing Budget

7. Results

The processing system for the Optical Communications demonstrator has been operating with good results. The Control Terminal software has been completed and is operating as expected. The System control Assembly's software has been developed to accommodate the available hardware, including command/control, diagnostic, and time critical functions. The system has been tested using simulated ephemerides data, all routines that run during the "Housekeeping" slots have been rigorously timed. Each of these functions can be executed within their allotted times without interruption of tracking.

7. CONCLUSION

In conclusion, the processor and software architecture for beacon acquisition and precision beam pointing in the reduced complexity Optical Communication Demonstrator was described. It was shown that by blending real-time and linear processing, a single processor can be used to perform all the in-flight command and control functions without interruption of tracking.

8. ACKNOWLEDGMENTS

This work was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. The author wishes to thank H. Ansari, S. Bruscoe, C. Chen, and K. Shaik for their discussions and help on implementing the software design. Many useful discussions were conducted with J. Lesh and D. Russell.

The author wishes to recognize the contribution and support provided by ARIEL corporation, especially by Steve Curtin, Don Elwell, Ed Travalia. Albert C. Johnson, with Innovation Products Inc. has also provided valuable support.

The TMS320C40 is manufactured by Texas Instruments; their development tools were extensively used for development of the SCA.

Turbovision is a trademark of Borland.

9. REFERENCES

1. C. C. Chen, H. Ansari, and J. R. Lesh, "Precision beam pointing for laser communication system using a CCD-based tracker," OE/Aerospace 93, SPIE Proceedings, Vol. 1949-15, 1993.
2. P. E. Papamichalis, *Digital Signal Processing Applications with the TMS320 Family*, Volume 3, Prentice Hall, 1990.